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Stromatolite research in Western Australia

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Abstract

Research on Western Australian stromatolites, both modern and ancient, has played an important role in the environmental and biostratigraphic interpretation of these enigmatic organosedimentary structures. This research has been concentrated on modern stromatolites from Hamelin Pool, Devonian stromatolites from the Canning Basin, and Proterozoic stromatolites from several areas of the State.

The first research on the Hamelin Pool stromatolites indicated that they are restricted to the intertidal zone, their morphology is controlled by environmental rather than biological factors, and they are formed solely by the trapping and binding of sedimentary particles by algal filaments. Using uniformitarian principles these conclusions were widely applied to ancient stromatolites, and as a corollary, many palaeontologists and stratigraphers concluded that stromatolites can be of no value for biostratigraphic correlation. However, each of these conclusions has subsequently been disproved or substantially modified.

Recent work at Hamelin Pool has now shown that living stromatolites there are not restricted to the intertidal zone as had previously been supposed; they grow to depths of at least 3.5 m. Indeed the subtidal occurrences are more widespread than those in the intertidal zone. Moreover, although the external morphology of stromatolites at Hamelin Pool is governed by environmental factors, their internal fabric is biologically controlled.

Stromatolites in the Devonian reef complexes of the Canning Basin grew through a wide depth range, from the intertidal zone to depths which probably exceeded 100 m. These stromatolites were not formed solely by enmeshing of clastic particles by algal filaments; biochemical precipitation of carbonate by algae and/or bacteria was also important, and was the only growth mechanism in some forms. The shallow- and deep-water stromatolites in these reef complexes have certain distinguishing morphological features which may also characterize other ancient stromatolites. The most distinctive of these is the presence of fenestral fabrics in shallow-water forms (also characteristic of Hamelin Pool stromatolites) and their absence in deep-water forms.

Western Australian Proterozoic stromatolites have been shown to have value for inter-regional correlations within Australia. However, some significant anomalies have been found in attempting to correlate with the standard stromatolite sequence in the Proterozoic of the Soviet Union, and there remains considerable doubt as to the extent to which stromatolites can be used for inter-continental correlation.

Introduction

Interest in the study of stromatolites has increased greatly among palaeontologists, sedimentologists, and biologists over the past 20 years, primarily because stromatolites are the principal macrofossils known from the Precambrian, and are potentially useful for biostratigraphic correlation and environmental interpretation.

However, there has been considerable controversy on the validity of correlations and environmental interpretations using stromatolites. Some authorities have maintained that the morphological characteristics of stromatolites are environmentally rather than biologically controlled, and that consequently stromatolite taxa are meaningless in biological terms, and biostratigraphic correlations based on them can have no validity. These workers commonly favour a stromatolite classification based on descriptive geometric formulae. Others believe that evolutionary changes must have occurred in the stromatolite-building algae, thereby resulting in recognizable changes in the stromatolites themselves through geological time. They claim that although environmental factors are often important in controlling the gross external morphology of stromatolites, their internal fabric is largely biologically controlled. These authorities use a binomial nomenclature of "group" and "form" in classifying stromatolites. They acknowledge that the terms "species" and "genus" should not be applied to stromatolites, as they have commonly been built by assemblages of algae and/or bacteria. Many of these workers believe that stromatolites are of considerable value for inter-regional and perhaps inter-continental correlations in the Precambrian. A recent comprehensive review of the status of world stromatolite research is contained in the volume edited by Walter (1976).

With regard to the environmental interpretation of stromatolites, some researchers have claimed that marine stromatolites are restricted to narrow environmental limits, being virtually confined to the intertidal zone. Others believe that stromatolites have grown through a very wide range of environments, from the supratidal zone to abyssal depths of the oceans.

Research on Western Australian stromatolites has played an important role in the history of debate on these critical aspects of stromatolite studies, and it is to these aspects that I will primarily direct this paper.

The term stromatolite as used in this paper is defined as an organosedimentary structure with vertical relief above the substrate produced by sediment trapping and/or precipitation resulting from the growth of micro-organisms, principally blue-green algae (slightly modified after Awramik 1977).

Historical review

The first description of stromatolites in Western Australia was by Clarke and Teichert (1946) dealing with wrinkled and bulbous structures in algal mats covering the floor of Lake Cowan, a dry salt lake near Norseman. Although Clarke and Teichert did not use the term stromatolite in describing these structures, they would be referred to as such by modern workers.

Fairbridge (1950) was the first to publish a description of ancient stromatolites from this State. He described Proterozoic silicified forms, which he referred to the genus *Collenia*, from what is now known as the Coomberdale Chert, in the area north of Moora. Logan and Chase (1961) subsequently described *Collenia undosa*, *C. columnaris*, and *Cryptozoon frequens* from this formation.

Logan (1961) published a paper dealing with the modern stromatolites of Hamelin Pool, an arm of Shark Bay; this was the first research on Western Australian stromatolites to receive international attention. The Hamelin Pool stromatolites are now recognized as being the best examples of living stromatolites known from modern seas, and the conclusions reached by Logan had a profound impact on stromatolite research for many years. Several subsequent papers have described these remarkable forms, including those by Logan *et al.* (1974), Hoffman (1976), and Playford and Cockbain (1976).

An attempt to use stromatolites for correlation of Proterozoic stromatolite-bearing sequences in Western Australia was published by Edgell (1964). He concluded, contrary to prevailing opinion in Australia at the time, that biostratigraphic correlations could be made using stromatolites, at least on an inter-regional level.

A varied assemblage of stromatolites and a series of large stromatolite bioherms have been described from the Devonian reef complexes of the Canning Basin by Playford and Cockbain (1969) and Playford *et al.* (1976). These are among the best-preserved stromatolites known from middle Palaeozoic rocks in the world. However, their unique importance lies in the fact that it has been possible to demonstrate the original water-depth relationships of the stromatolites, and to formulate criteria for distinguishing deep-water and shallow-water forms.

Modern studies of Proterozoic stromatolites in Western Australia began with the monograph by Walter (1972), in which he described forms from the Hamersley, Bangemall, and Ord Basins in Western Australia, and from other Australian basins. Walter applied methods of stromatolite study developed in Russia, where stromatolites have been studied more intensely than in other countries and have been widely used for inter-regional Precambrian correlations.

The most recent work on Proterozoic stromatolites in Western Australia is by Preiss (1976), describing forms from the Nabberu and Officer Basins. This work is important principally because of the doubt that it casts on the validity of inter-continental correlations in the Proterozoic based on stromatolite groups.

Modern stromatolites at Hamelin Pool

Introduction

Hamelin Pool is a marine barred basin consisting of a broad central area 5 to 10 m deep, surrounded by a sublittoral platform up to 5 km wide, backed by intertidal-supratidal flats. The basin is barred to the north by the Faure Sill, a sand and seagrass bank cut by a number of prominent tidal-exchange channels. The high evaporation and low precipitation in the area, combined with the restricted inflow of normal oceanic water because of the Faure Sill, has caused the waters of Hamelin Pool to become hypersaline, with salinities ranging from 55‰ to 70‰ throughout the year.

Stromatolites were first recognized around the shores of Hamelin Pool by geologists of West Australian Petroleum Pty Ltd in 1954-55, and the first published description of them was by Logan (1961). This paper and the subsequent paper by Logan *et al.* (1964) stimulated interest in the study of stromatolites around the world, and their conclusions greatly influenced the interpretation of ancient stromatolites. As a result it became widely accepted that stromatolites are essentially confined to the intertidal zone, that their morphology is environmentally rather than biologically controlled, and that they have formed solely by the trapping and binding of particulate sediment by algal filaments without any biochemical precipitation. Moreover, because of the supposed lack of biological control on stromatolite morphology, it was generally believed that biostratigraphic correlations based on stromatolite taxa could have no validity. However, each of these conclusions, founded largely on the early work at Hamelin Pool, has since been disproved or substantially modified.

Distribution

Living stromatolites extend discontinuously around the shores of Hamelin Pool from the intertidal zone to depths of at least 3.5 m on the sublittoral shelf. Logan (1961) had claimed that the Hamelin Pool stromatolites are confined to the intertidal zone, and that as a result the maximum height of individual columns cannot exceed the mean tidal range (about 0.6 m). This conclusion was confirmed by Logan *et al.* (1964) and was extended to embrace stromatolites in the ancient record. However, subsequent work (first reported by Playford 1973) has shown that subtidal stromatolites are widespread at Hamelin Pool.

Logan *et al.* (1974) reported that large subtidal stromatolites occur at a few localities in Hamelin Pool, extending to depths of about 2 m, but concluded that these forms could be "relict" structures which grew originally in the intertidal zone at a time when sea level was lower than it is today. Hoffman (1976), in a summary of this paper, also recorded subtidal stromatolites to depths of 2 m, but he did not imply that they were relics of an earlier low sea level.

Playford and Cockbain (1976) observed that contrary to previous reports, living stromatolites and flat algal mats are widespread over the sublittoral platform fringing Hamelin Pool, and that the stromatolites extend to depths of at least 3.5 m. Furthermore, subsequent observations utilizing low-level colour air photos show that subtidal stromatolites and algal mats at Hamelin Pool are more extensive than the intertidal forms.

In many areas of Hamelin Pool living stromatolites are backed by dead forms in the supratidal zone, and these reach 0.5 to 1 m above mean sea level, commonly forming a series of stepped terraces (Playford and Cockbain 1976). These dead stromatolites are in varying stages of disintegration, and they must have emerged in relatively recent times (perhaps only several hundred years ago). It is uncertain whether this emergence has resulted from tectonic uplift or eustatic falls in sea level, but there is increasing evidence for Holocene tectonism in this part of the Carnarvon Basin, and tectonic emergence of the dead stromatolites is therefore likely.

Morphology and biology

Logan (1961) emphasized environmental controls on stromatolite morphology at Hamelin Pool, but he did not distinguish the various types of stromatolite-building algal mats and the internal fabrics resulting from those mats. It was later shown by Logan *et al.* (1974) and Hoffman (1976) that there are three types of algal mat that build stromatolites at Hamelin Pool: pustular mat in the middle to upper intertidal zone, smooth mat in the lower intertidal zone, and colloform mat in the lower intertidal to subtidal zone. Each of these mats is built by a characteristic association of algae; pustular mat is dominated by *Entophysalis major*, smooth mat by *Schizothrix helva*, and colloform mat by *Microcoleus tennerimus*. These authors also showed that the internal fabrics of stromatolites resulting from the three mat types are different.

These observations on mat distribution and on the relationships between mat types and internal fabrics were generally confirmed by Playford and Cockbain (1976). However, more recent observations show that pustular mat extends from the upper intertidal zone into the shallowest subtidal zone, smooth mat is characteristic of the middle to lower intertidal and shallow subtidal zones (extending deeper than pustular mat), and colloform mat is restricted to subtidal environments, reaching depths of at least 3.5 m. Thus there is a generalized zonation of pustular mat dominating the shallowest environments, followed successively moving into deeper water by smooth mat and colloform mat. Pustular mat results in massive or crudely layered, irregular, coarse fenestral fabrics, smooth mat in laminated fine fenestral fabrics, and colloform mat in weakly laminated, coarse fenestral fabrics.

The most characteristic feature of the Hamelin Pool stromatolites is the occurrence of fenestral fabrics, the largest fenestrae being found in stromatolites formed by pustular mat, and the smallest in those formed by smooth mat. The best-developed lamination is formed by smooth mat, while the poorest results from pustular mat.

Monty (1976) and Golubic (1976) give further details of some aspects of the microstructure and internal fabrics of Hamelin Pool stromatolites and of their biological characteristics.

Logan (1961) concluded that discrete stromatolites occur characteristically around headlands, whereas flat algal mats occur in bays, and this was generally confirmed by Logan *et al.* (1974) and Hoffman (1976). They observed that stromatolites at Hamelin Pool are commonly elongate in the direction of wave translation, approximately normal to the shoreline, and deduced that such elongation in ancient stromatolites is likely to have a similar origin. They also reported that some stromatolites "lean" seaward in the direction of wave translation. Hoffman (1976) noted further that stromatolites in some areas of Hamelin Pool occur in belts parallel to the shorelines, but gave no explanation for this alignment.

Playford and Cockbain (1976) found that although intertidal stromatolites in some areas are concentrated around headlands, in others they are extensively developed in bays. They also found that subtidal stromatolites are widespread in front of both headlands and bays. It now seems that the main requirement for the extensive development of stromatolites at Hamelin Pool is that there be a rocky substrate. This is generally formed of calcrete (over Pleistocene deposits or Cretaceous chalk), or Tertiary Lamont Sandstone, or lithified Pleistocene beach ridges. Where stromatolites have been localized by beach ridges, they occur in curved bands which are often approximately parallel to the present coastline.

Playford and Cockbain (1976) confirmed that individual stromatolites are generally oriented in the direction of wave movement, perpendicular to the shore. However, they also demonstrated that in some areas rows of stromatolite ridges have grown parallel to the prevailing wind and that the "leaning" intertidal stromatolites lean towards the wind rather than in the direction of wave movement. It appears that the stromatolite ridges (here termed "seif stromatolites") have formed in response to helical water vortices induced in shallow water by strong prevailing southerly winds. These ridges exhibit "tuning fork junctions" opening upwind, and in this respect they resemble subaerial seif dunes (which are thought to have resulted from helical air vortices). However, the mechanism whereby the prevailing wind controls the inclination of "leaning" stromatolites is not fully understood.

Lithification of the Hamelin Pool stromatolites is occurring in both intertidal and subtidal environments, contrary to the suggestion of Logan (1961) that exposure in the intertidal zone is required for the induration of stromatolites. The particulate sediment that has been trapped and bound by algae is being cemented a few millimetres or centimetres below the surface by microcrystalline aragonite. Detailed studies have not yet been carried out on the cementing process to determine whether or not it is wholly or partly biochemical, but it seems likely that algal or bacterial action is at least partly responsible for the aragonite precipitation.

Stromatolites at Hamelin Pool commonly form linear reefs controlled by the existing shoreline or by indurated submerged beach ridges. These reefs are rigid and wave resistant but they lack the skeletal framework required by many reef definitions, having been built by non-skeletal algae. The Hamelin Pool occurrences clearly demonstrate the way in which stromatolites and other cryptalgal bodies, when subject to early cementation, can form rigid wave-resistant bodies, and there is no good reason why these should not be considered as representing a type of organic reef. Many Proterozoic reefs and some Palaeozoic reefs were apparently formed in this way.

Growth rates

Growth-rate studies on intertidal and subtidal stromatolites at Hamelin Pool show that the living forms grow very slowly. The maximum rate of growth observed is less than 1 mm per year, and many forms appear to have virtually reached a state of equilibrium, with growth approximately balanced by erosion (Playford and Cockbain 1976). It is likely that many of the living stromatolites are many hundreds of years old.

Tracks cut through the stromatolites by horse- and camel-drawn wagons (when goods were transported to and from stations around Hamelin Pool by lighter) are still clearly defined at several localities, little or no regrowth of stromatolites having occurred in the tracks since they were last used during the 1930s. This emphasizes the susceptibility of the Hamelin Pool stromatolites to damage by human activities (Department of Environmental Protection 1975, Playford 1976a).

Classification

A geometric system of stromatolite classification, based on the arrangement of crude hemispheroids and spheroids, was proposed by Logan *et al.* (1964), using the Hamelin Pool stromatolites as a principal example. This classification has been widely used, especially among sedimentologists. However, it does not take into account the internal fabric and microstructure of stromatolites, and is regarded as inadequate for detailed studies by many workers (Walter 1972).

Modern stromatolite specialists who have adopted a biostratigraphic approach to stromatolite research commonly use the Russian binomial taxonomy of "group" and "form" in classifying fossil stromatolites. As yet no one has attempted to apply this classification to the Hamelin Pool stromatolites. However, as pointed out by Playford and Cockbain (1976), they could form an excellent basis for testing principles of stromatolite classification, as the diverse living stromatolites have been built by several mat types and extend through a range of environments. If the taxonomic principles applied to fossil stromatolites have any biological validity they should also be applicable to the modern Hamelin Pool stromatolites.

Hamelin Pool stromatolites: is the present the key to the past?

The barred basin forming Hamelin Pool represents an unusual environment in modern seas, and the unique occurrence there of flourishing stromatolites is linked to the hypersalinity of this environment. Hypersalinity has caused a major reduction in the number of metazoan species in Hamelin Pool compared with adjoining less-restricted areas of Shark Bay. A few euryhaline species (such as the bivalve *Fragum erugatum* and various fish) are abundant in Hamelin Pool, but it is clear that algae grazers (especially gastropods) are much reduced. This allows stromatolites and associated algal mats to flourish in Hamelin Pool, whereas elsewhere, in waters of more normal oceanic salinity, they tend to be "nipped in the bud" by metazoan grazers.

The reduction in algae-consuming organisms in Hamelin Pool resembles the situation that prevailed in the world's oceans during the Proterozoic, when few metazoans had developed, allowing stromatolites to develop widely. Stromatolites subsequently declined progressively during the Phanerozoic, as animal life diversified and became more abundant, until today Hamelin Pool is the principal remaining stronghold of marine shallow-water stromatolites in the world.

The history of stromatolite research at Hamelin Pool illustrates the dangers inherent in uncritical acceptance of modern environments as definitive guides to the past, especially when those environments are themselves imperfectly known. Uniformitarian application of the original Hamelin Pool stromatolite model led to the widespread but mistaken belief that ancient stromatolites are strictly intertidal phenomena and their morphology is controlled solely by environmental factors.

Apart from the fact that the original Hamelin Pool observations were inaccurate, there can be no justification for assuming that all ancient stromatolites have formed under conditions resembling those in Hamelin Pool today. The factor of prime importance in development of the Hamelin Pool stromatolites is hypersalinity, and although some ancient stromatolites can be shown to have formed in hypersaline environments, this was not the case for most ancient stromatolites.

This is not to say that the Hamelin Pool stromatolites are of no value in understanding ancient stromatolites. Quite to the contrary, they have much to teach us about stromatolite growth mechanisms and biological and environmental controls on stromatolite morphology. This information is an important aid in interpreting ancient stromatolites, but what needs to be emphasized is that evidence for the reconstruction of ancient environments must be sought primarily in the ancient rocks themselves. Environments that favoured stromatolites in the past do not favour them today; the present is thus only partly a key to the past.

Devonian stromatolites in the Canning Basin

Introduction

Algal stromatolites are important constituents of the Devonian reef complexes of the Canning Basin. These complexes form a barrier-reef belt which extends for about 300 km along the northern margin of the basin, adjoining the Precambrian Kimberley Block. They range from Middle to Late Devonian in age.

Three basic facies are recognized in the complexes: platform, marginal-slope, and basin facies. There are also several named sub-facies, the most important being the reef-margin, reef-flat, back-reef, reefal-slope, and fore-reef sub-facies (Playford 1976b).

The platforms were for the most part built by stromatoporoids, corals, and algae in the Givetian and Frasnian, and by algae in the Famennian. The platform deposits accumulated in near-horizontal beds, commonly with a massive or crudely bedded reef margin. The platforms stood some tens to hundreds of metres above the surrounding inter-reef basins, and were flanked by steeply dipping marginal-slope deposits composed largely of platform-derived debris, with contributions from indigenous organisms and terrigenous sources. Depositional dips in these deposits were commonly up to 35-40° in loose sediments, and up to vertical where algal binding and precipitation occurred together with early lithification. At the foot of the slopes the marginal-slope deposits interfingered with the flat-lying basin deposits, composed largely of terrigenous material.

Stromatolites occur in the reef complexes in the platform and marginal-slope facies (Playford and Cockbain 1969; Playford 1973; Playford *et al.* 1976). In a few areas they extend from the marginal-slope deposits into the adjoining part of the basin facies. Those that occur in the platform facies are believed to have grown in shallow water (less than about 5 m in depth), while the others have grown in relatively deep water (to depths of 100 m or more).

Shallow-water stromatolites

Shallow-water stromatolites and other cryptalgal limestones are widespread in the platform facies of the reef complexes, where they are commonly the principal rock builders, especially in the younger Frasnian and Famennian complexes. Columnar forms occur most frequently in the reef-margin sub-facies, and flat-bedded algal-mat deposits and oncolites are common in the back-reef sub-facies. Fenestral fabrics are characteristic of the shallow-water stromatolites and other cryptalgal deposits of the platform facies, but are absent in the deep-water stromatolites.

The columnar stromatolites of the platform facies closely resemble the modern Hamelin Pool stromatolites in both external morphology and internal fabric. The close similarity between the fenestral fabrics of these Devonian and modern forms is very striking (Playford *et al.* 1976). It is believed likely that such fenestral fabrics are characteristic of shallow-water stromatolites, both modern and ancient.

Deep-water stromatolites

Stromatolites are conspicuous features of some parts of the marginal-slope facies, extending into adjoining parts of the basin facies, and they also occur capping drowned reefs and allochthonous reef blocks.

The marginal-slope stromatolites grew on slopes with original inclinations ranging from a few degrees up to near vertical. Stromatolitic algae are believed to have been responsible for maintaining those depositional slopes that exceeded the angle of rest (35-40°) for loose debris. Both skeletal and non-skeletal algae were involved in the construction of the stromatolites, recognizable forms including *Sphaerocodium*, *Renalcis*, *Girvanella*, and *Frutexites* (although some authorities regard *Renalcis* as a foraminifer rather than an alga).

The deep-water stromatolites are considerably more diverse than the shallow-water forms in the reef complexes. Playford *et al.* (1976) recognized spaced columnar, contiguous columnar, branching columnar, longitudinal, scalloped, reticulate, undulous, and domal deep-water forms. In addition, large stromatolite bioherms up to 1 km across are developed in some areas, overlying drowned stromatoporoid-algal pinnacle reefs. The most impressive of these occur near Elimberrie Spring in the Oscar Range. Similar

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stromatolite cappings, but on a much smaller scale, occur on top of allochthonous reef blocks (derived from platform margins) in the marginal-slope facies.

Depth relationships of the deep-water stromatolites have been deduced from palaeobathymetric reconstructions. The depositional and post-depositional components of an observed dip in marginal-slope deposits can be determined using geopetal fabrics (Playford *et al.* 1976), and on this basis palaeobathymetric measurements can be made. Thus, where an observed dip in marginal-slope deposits is solely depositional the difference in water depth between any two points on a bedding plane is the same as the present elevation difference between them. Appropriate corrections are made where post-depositional tilting is involved. This method has been applied at several localities where stromatolites occur in situ in marginal-slope deposits, and reconstructions indicate that some of the deep-water stromatolites must have grown in water as deep as 100 m or more.

Well-developed deep-water stromatolites are associated with strongly condensed sequences (i.e. very slow deposition). They grew on those areas of the marginal slopes that were receiving very little sediment and on bare elevated features such as drowned pinnacle reefs and allochthonous reef blocks. They are best developed in the Frasnian-Famennian Virgin Hills and Napier Formations, especially in the early Famennian parts. Evidence for the condensed nature of the stromatolite-bearing horizons is provided by conodont zones, which are very much thinner than in equivalent sections lacking stromatolites. It is deduced that the stromatolites grew very slowly; the average annual growth rate may commonly have been as low as 2 μm.

Many of the deep-water stromatolites in the Canning Basin reef complexes are coloured bright red, due to the presence in them of finely divided iron oxide (mainly hematite). In some stromatolites there is a pronounced concentration of iron oxide in and around algal filaments, especially those of the genus *Frutexites,* in which the iron content may be as high as 30%. Other algae which commonly show iron concentration are *Girvanella* and (to a lesser extent) *Sphaerocodium*. Microprobe analysis indicates that low concentrations of manganese also occur with the iron-rich filaments. It is believed that bacteria living in association with the algae are most likely to have been responsible for this iron and manganese deposition.

The columnar deep-water stromatolites commonly grew approximately vertically, either towards the light (phototropic) or under the influence of gravity (geotropic). It is not known whether all the stromatolitic organisms were photosynthetic; some stromatolites could have been formed by heterotrophic algae or bacteria.

The deep-water stromatolites grew as hard and rigid bodies; many are encrusted by crinoid and coral holdfasts, and some show evidence of early fracturing, the fractures being filled with early submarine cement or sediment, forming neptunian dykes. Some of the stromatolites have formed primarily through the trapping and binding of clastic particles (including terrigenous detritus) by non-skeletal algae (and/or bacteria) associated with biochemical or inorganic precipitation of cement. Others contain little or no clastic material and such stromatolites were formed primarily or wholly by algal precipitation of carbonate.

Apart from the sessile crinoids and corals mentioned above, the fauna of the condensed sequences associated with the stromatolites is characterized by open-marine pelagic organisms: conodonts, ammonoids, and nautiloids. These fossils are often very abundant, especially in the interareas between stromatolites.

Characteristics of shallow-water and deep-water stromatolites

The characteristics of deep-water stromatolites in the Canning Basin reef complexes are distinctly different from those of the shallow-water forms. These differences are summarized in Table 1. It is suggested that many of these features may be applicable in other parts of the stratigraphic record for distinguishing between shallow- and deep-water stromatolites.

Table 1

Characteristics of deep-water and shallow-water stromatolites in the Canning Basin

Deep-water stromatolites	Shallow-water stromatolites
Fenestral fabrics absent	Fenestral fabrics common
Usually finely laminated	Usually weakly laminated or unlaminated
Diverse assemblage of forms	Columnar forms only, associated with oncolitic and fenestral limestones
In condensed sequences	Not in condensed sequences
Grew on depositional slopes, drowned reefs, and allochthonous blocks	Grew on near-horizontal limestone platforms
Pelagic faunas common	Associated with reefal and biostromal organisms, especially stromatoporoids and *Renalcis*
Some forms encrusted with crinoids and corals	Not encrusted by corals or crinoids
Iron and some manganese precipitation important in certain forms	No significant iron or manganese precipitation
Commonly red or reddish brown	Commonly white or pale yellow

The deep-water stromatolites show some resemblance to ferromanganese deep-water bacterial stromatolites known from modern seas (Monty 1973). Both occur in condensed sequences, are generally finely laminated, lack fenestral fabrics, and are associated with pelagic faunas. Iron and manganese concentrations also occur in both, but these concentrations are much higher in the modern ferromanganese stromatolites.

Proterozoic stromatolites

During the late 1960s the University of Adelaide became the main centre of Precambrian stromatolite research in Australia, under the direction of M. F. Glaessner. He introduced principles of stromatolite classification and methods of stromatolite reconstruction based on serial sectioning that had been applied for some time in the Soviet Union, where stromatolites had been used extensively for Precambrian correlations. Two of his students, M. R. Walter and W. V. Preiss, began a wide-ranging study of Australian Precambrian stromatolites, which is still continuing. Their two principal publications which deal with Western Australian forms are by Walter (1972) and Preiss (1976). K. Grey of the Geological Survey of Western Australia is also conducting research on Precambrian stromatolites from this State.

Walter (1972) described stromatolites from the Early Proterozoic Fortescue Group (ca. 2 400 m.y.) of the Hamersley Basin, the Early Proterozoic Wyloo Group (ca. 1 900 m.y.) of the Ashburton Trough, the Middle Proterozoic Bangemall Group (ca. 1 000 m.y.) of the Bangemall Basin, and the latest Proterozoic or earliest Cambrian Antrim Plateau Volcanics of the Ord Basin.

In addition to these Western Australian occurrences Walter also described Proterozoic stromatolites from the Amadeus, McArthur and Georgina Basins of the Northern Territory and Queensland. His results suggested that stromatolites could be used for inter-regional correlation within Australia, but he noted some anomalies in correlations with the Russian sequence. One of the stromatolite groups *(Patomia)* he recorded in the Early Proterozoic Wyloo Group is indistinguishable from a Late Proterozoic (Vendian) form in the Soviet Union.

Preiss (1976) described an assemblage of Proterozoic stromatolites from the Nabberu and Officer Basins in Western Australia. The Nabberu Basin occurrences are in the Early Proterozoic Earaheedy Group (at least 1 700 m.y.), while those from the Officer Basin are from Woolnough Hills and "Central Neale" (near Yeo Lake) in rocks which may correlate with the Ilma Beds (probable Late Proterozoic).

The stromatolite groups recorded from the Officer Basin are consistent with the expected Late Proterozoic age, based on correlation with other stromatolite occurrences of this age in South Australia. However, the Early Proterozoic Nabberu Basin stromatolites are anomalous, as the stromatolite groups present have only previously been recorded elsewhere from Late Proterozoic rocks—*Minjaria* from the Late Riphean, and *Tungussia* from the Middle Riphean to Vendian of the Soviet Union. *Kulparia,* another form which may be present (recorded as ?cf. *Kulparia*), is known elsewhere in Australia from Late Riphean or Vendian equivalents. It therefore seems that the time range of these stromatolite groups is considerably longer than had previously been believed, assuming that the 1 700 m.y. dating (K/Ar based on glauconite) is correct.

Consequently, Preiss (1976, 1977) advocates caution in dating Precambrian sediments on the basis of stromatolites alone, especially where correlations are made using stromatolite groups rather than forms. Although the Russian biostratigraphic scheme based on stromatolites appears to have validity throughout the Soviet Union, detailed stromatolite studies are still in their infancy in most other countries, and it remains to be seen how much of the Russian biostratigraphy can be applied on an intercontinental scale.

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References

Awramik, S. M. (1977).—Paleobiology of stromatolites. *In* Chemical evolution of the early Precambrian. Academic Press, New York: 111-131.

Clarke, E. de C. and Teichert, C. (1946).—Algal structures in a Western Australian salt lake. *Amer. Jour. Sci.* 244: 271-276.

Department of Environmental Protection (1975).—Conservation of Hamelin Pool, Western Australia. West. Australia Dept Environmental Protection Publication, 21p.

Edgell, H. S. (1964).—Precambrian fossils from the Hamersley Range, Western Australia, and their use in stratigraphic correlation. *Geol. Soc. Australia Jour.* 11: 235-261.

Fairbridge, R. W. (1950).—Pre-Cambrian algal limestone in Western Australia. *Geol. Mag.* 87: 324-330.

Golubic, S. (1976).—Taxonomy of extant stromatolite-building cyanophytes. *In* Stromatolites, M. R. Walter (editor), Developments in Sedimentology, v.20, Elsevier: 127-140.

Hoffman, P. (1976).—Stromatolite morphogenesis in Shark Bay, Western Australia. *In* Stromatolites, M. R. Walter (editor), Developments in Sedimentology, v.20, Elsevier: 261-271.

Logan, B. W. (1961).—*Cryptozoon* and associate stromatolites from the Recent, Shark Bay, Western Australia. *Jour. Geology* 69: 517-533.

Logan, B. W. and Chase, R. L. (1961).—The stratigraphy of the Moora Group, Western Australia. *Roy. Soc. West. Australia Jour.* 44: 14-32.

Logan, B. W., Hoffman, P. and Gebelein, C. D. (1974).—Algal mats, cryptalgal fabrics, and structures, Hamelin Pool, Western Australia. *Amer. Assoc. Petroleum Geologists Memoir* 22: 140-194.

Logan, B. W., Rezak, R. and Ginsburg, R. N. (1964).—Classification and environmental significance of algal stromatolites. *Jour. Geology* 72: 68-83.

Monty, C. L. V. (1973).—Les nodules de manganese sont stromatolithes oceaniques. *Acad. Sci. Paris Compte Rendus* Series D, 276: 3285-3288.

Monty, C. L. V. (1976).—The origin and development of cryptalgal fabrics. *In* Stromatolites, M. R. Walter (editor), Developments in Sedimentology, v.20, Elsevier: 193-259.

Playford, P. E. (1973).—Algal stromatolites in the Devonian of the Canning Basin, Western Australia. *Soc. Geol. Belgique Annales* 95: 401-402.

Playford, P. E. (1976a).—Conservation of modern stromatolites at Hamelin Pool, Western Australia. *Stromatolite Newsletter* 4: 6-16.

Playford, P. E. (1976b).—Devonian reef complexes of the Canning Basin, Western Australia. *25th Int. Geol. Congress Excursion Guide* 38A.

Playford, P. E. and Cockbain, A. E. (1969).—Algal stromatolites: deep-water forms in the Devonian of Western Australia. *Science* 165: 1008-1010.

Playford, P. E. and Cockbain, A. E. (1976).—Modern algal stromatolites at Hamelin Pool, a hypersaline barred basin in Shark Bay, Western Australia. *In* Stromatolites, M. R. Walter (editor), Developments in Sedimentology, v.20, Elsevier: 389-411.

Playford, P. E., Cockbain, A. E., Druce, E. C., and Wray, J. L. (1976).—Devonian stromatolites from the Canning Basin, Western Australia. *In* Stromatolites, M. R. Walter (editor), Developments in Sedimentology, v.20, Elsevier: 543-563.

Preiss, W. V. (1976).—Proterozoic stromatolites from the Nabberu and Officer Basins, Western Australia, and their biostratigraphic significance. *South Australia Geol. Survey Rept. Investigations* 47, 51p.

Preiss, W. V. (1977).—The biostratigraphic potential of Precambrian stromatolites. *Precambrian Research* 5: 207-219.

Walter, M. R. (1972).—Stromatolites and the biostratigraphy of the Australian Precambrian. *Palaeontol. Assoc. London, Spec. Paper* 11, 190p.

Walter, M. R. (editor) (1976).—Stromatolites. Developments in Sedimentology, v.20, Elsevier, 790p.